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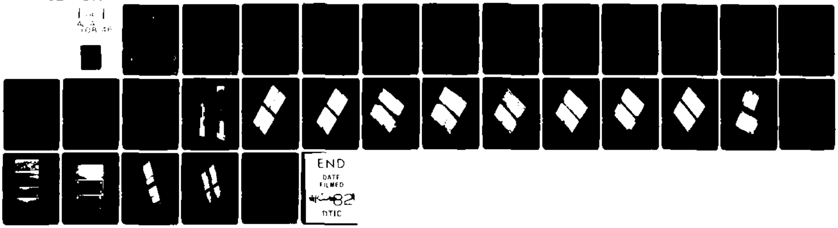

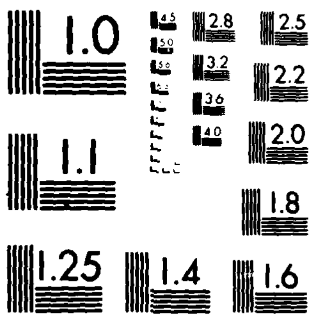

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AD A108146

SHIPBOARD EXPOSURE TESTING

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An effort is underway to correlate results of accelerated laboratory corrosion tests with actual shipboard exposure of aircraft materials. This report compares results of corrosion tests of a series of aluminum alloys with varying degrees of exfoliation resistance exposed on the flight decks of nuclear and conventional carriers. Results of exposure of laser hardening paints, water displacing paint, aluminum/aluminum oxide and graphite/epoxy composites are also described. Additionally, results of initial laboratory tests are given.

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INTRODUCTION

Under reference (a), various aircraft materials are being exposed to the environment on aircraft carrier flight decks. The objective is to provide baseline information for the development of a realistic accelerated laboratory corrosion test as well as to evaluate materials projected for use on Naval aircraft.

The first materials tested were exposed on a rack attached to the radar tower on the flight deck of the U.S.S. John F. Kennedy, a conventional, oil burning carrier. Aluminum alloy plate materials for the tests were obtained from a joint interlaboratory ASTM/Aluminum Association testing program. These alloys had been heat treated to provide varying degrees of susceptibility to exfoliation. Results of KENNEDY exposure tests are given in reference (b).

The environment of a conventional oil burning aircraft carrier includes stack gas exhaust products as well as sea spray. One of these products is sulfur dioxide. The conventional carrier could therefore be said to have the combined effect of industrial and marine environments. On the other hand, a nuclear aircraft carrier has no stack gases and should provide only a marine environment.

This report contains results of exposure tests aboard the U.S.S. Nimitz, a nuclear carrier, and the U.S.S. Constellation, another conventional carrier. Aluminum alloy specimens from the same materials exposed on the U.S.S. John F. Kennedy were exposed on the other two carriers as controls. Results of aluminum alloy corrosion from the three carrier runs are compared, and some of the results obtained with other materials are discussed.

DESCRIPTION OF TESTS

MATERIALS

Exfoliation Specimens

The same aluminum alloy materials used for exposure specimens on the U.S.S. John F. Kennedy were used for exposure on the U.S.S. Nimitz and the U.S.S. Constellation. Table I lists the specimens. The 50.8 mm plate of 2124 aluminum alloy was machined in three steps to expose the varying thicknesses (T) of T/10, T/4, and T/2. The 12.7 mm plate of 2124, and the 7075 and 2024 extensions were machined to expose the T/10 and T/2 planes. The 7178 aluminum alloy plate had only the T/10 plane exposed.

Graphite Epoxy Composite Specimens

Nine 24.1 x 22.9 cm (9½" x 9") graphite epoxy panels were prepared with the AS/3501-6 system, 16 ply 0, ±45, 90. Three were saved for controls. Six were painted with one coat of MIL-P-23377 epoxy primer and two coats of MIL-C-81773 polyurethane topcoat. Three of the painted panels were exposed on the NIMITZ and three on the CONSTELLATION.

Tensile, short beam shear, and flexural strength specimens were prepared from the exposed panels and compared with specimens prepared from the unexposed control panels. Tensile tests were conducted in accordance with ASTM D 3039, short beam shear in accordance with ASTM D 2344, and flexural strength in accordance with Federal Standard 406, Method 1031. Each of the tests was conducted at room temperature, 82.2°C (180°F), and 121.1°C (250°F).

Avionics Components

As part of the avionics corrosion control effort under reference (c), several avionics components supplied by the McDonnell Douglas Aircraft Company were exposed on the NIMITZ and CONSTELLATION racks. Results obtained with these specimens are being reported under reference (c).

Water Displacing Paint

Aluminum alloy panels 7.6 x 15.2 cm (3" x 6"), of clad 2024-T3 aluminum alloy were painted with water displacing paint which is being developed under reference (d). The painted panels were scribed down to the basis metal prior to exposure.

Aluminum Oxide/Aluminum Composite Materials

Two small samples of aluminum oxide/6061 aluminum alloy composite material were exposed on the CONSTELLATION rack. One was produced by powder metallurgy methods, one by liquid infiltration.

Laser Hardening Coatings

Laser hardening coatings consisting of a clear acrylic lacquer were applied to four chromated 7.62 x 15.24 cm (3" x 6") clad 7075-T6 aluminum alloy panels and overcoated with 7.6 μm (0.3 mil) of MIL-C-8514 wash primer, one coat of MIL-P-23377 primer, and two coats of MIL-C-81773 polyurethane topcoat. The panels were then exposed for eight months on the CONSTELLATION rack. These panels were not scribed prior to exposure.

The coated panels were furnished by Vought Corporation under a Navy contract. The bath used for applying the MIL-C-5541 chromate conversion coating was diluted with water so that the coating would be thinner than normal for coatings of this type. The clear acrylic was applied to a thickness of 25.4 μm (1 mil), the epoxy primer and polyurethane topcoat to the normal thicknesses applied to aircraft.

Exposure Racks

Racks, designed to expose the specimens at an angle of 45°, were fabricated from steel, cadmium plated, chromated, and painted with MIL-P-23377 epoxy primer and MIL-C-81773 polyurethane topcoat. The racks were approximately 2.4 metres long by 0.30 metre wide (8' x 1'). The NIMITZ rack was welded to the inboard side of the radar tower aft of the island on the flight deck. The rack was about 3.6-4.3 metres (12'-14') above the deck. A similar rack was installed in the same location on the radar tower of the CONSTELLATION. Specimens were attached to the racks with nylon bolts. MIL-S-8802 sealant was applied in the bolt holes and under the bolt heads to avoid crevice corrosion. Racks with specimens attached are shown in Figure 1.

Deployment

The U.S.S. Nimitz was deployed first to the Mediterranean from July 1979 to December 1979 and then to the Indian Ocean from January 1980 to May 1980. At the end of the ten month cruise, the ship returned and the specimens were removed from the rack.

The U.S.S. Constellation was deployed in the Western Pacific and the Indian Ocean from February to October 1980. Specimens were removed at the end of eight months. No interim inspections were made in either case.

Cyclic SO_2 – Salt Spray Tests

In an attempt to reproduce the type of exfoliation attack that took place on the carriers, 7075 and 2124 panels with low resistance to exfoliation were subjected to cyclic SO_2 – salt spray tests. Four different cycles were tried:

Cycle I
½ hr salt spray
1½ hr soak (no spray – no SO_2)*
1 hr SO_2 introduction

Cycle II
½ hr salt spray
½ hr SO_2
1 hr soak

Cycle III
½ hr salt spray
½ hr SO_2
2 hr soak

Cycle IV
½ hr salt spray + SO_2 (both together)
2½ hr soak

All panels were exposed in 45 degree racks.

RESULTS AND DISCUSSION

Exfoliation Tests

Results of the exfoliation tests of aluminum alloys are given in table II for all three carriers. The panels were rated according to ASTM G 34-79. The appearance of a typical NIMITZ exposure panel compared to a typical KENNEDY panel for each group is shown in figures 2 to 9. Figure 10 shows typical exposure panels from the CONSTELLATION. All alloys heat treated for high resistance to exfoliation showed only surface pitting attack and are therefore not shown in the figures.

Results of exposure on the NIMITZ were surprising in that corrosion was worse than it had been for the same materials exposed on the KENNEDY. The difference in behavior was attributed to the effect of temperature. The nuclear carrier was in the Indian Ocean for five months where temperatures ranged from 80 to 95°F. The first conventional carrier was in the Mediterranean for its entire deployment where temperatures were 20 to 30 degrees lower most of the time. In the Indian Ocean, there was little rain to wash off salt accumulations. With the sun shining on the panels, surface temperatures could be much higher than ambient.

It was unfortunate that no interim inspection on the nuclear carrier was possible. Four month inspection data from the first carrier showed slight corrosion occurring to that point, most took place in the last four months. Since the nuclear carrier was in the Mediterranean for the first five months also, it is not unreasonable to assume corrosion attack was also slight until the ship moved to the Indian Ocean.

*During the "soak" part of the cycle the panels were left in the closed cabinet with no sulfur dioxide being introduced and no salt solution being sprayed.

That the temperature effect is more important than the effect of stack gases was verified by the results from the third carrier. This was a conventional carrier with stack gases, but was in the Indian Ocean for three months and in the warmer regions of the Western Pacific for the remainder of its cruise. The attack on the low resistance 2124 – 0.5 in. particularly resembled that of the nuclear carrier.

Results with the aluminum alloys show that the environment of an aircraft carrier, however powered, is considerably more corrosive than seacoast or industrial environments. This is vividly demonstrated in figure 11 which is based on data from Sprowls et al., reference (e). It took only eight months on a carrier to develop severe exfoliation corrosion on susceptible alloys whereas at the most severe seacoast location (Point Judith, Rhode Island) it took 12 months and in the most severe industrial location (Brookfield, Illinois) 3 years.

Graphite/Epoxy Composite Specimens

Results of tests of the graphite/epoxy composite panels are given in table III. Based on the weight of one of the NIMITZ panels before and after exposure approximately 0.6 percent moisture pick-up resulted from the 10-month period of exposure. The effect of moisture pick-up is shown by the results in table III. NIMITZ specimens showed a decrease of about 2 percent in tensile strength at 121.1°C (250°F), a decrease of 29 percent in short beam shear strength, and a decrease of 13 percent in flexural strength. Decreases of this type are typical of graphite/epoxy at elevated temperature after moisture pick-up. Decreases were also shown by the panels exposed on the CONSTELLATION. The increase in strength at 82.2°C (180°F) for the NIMITZ panels is difficult to explain. Some post-curing may have taken place, accounting for the increase.

Aluminum Oxide/Aluminum Composites

Eight months of exposure on a conventional carrier resulted in only slight pitting of the aluminum oxide/6061 aluminum composites. Attack was equivalent to that observed on the aluminum alloy specimens heat treated to have high resistance to exfoliation corrosion. Metallographic examination of the mounted and polished cross sections of the panels revealed preferential attack on the matrix but no deep attack or obvious detrimental effect. There was slightly more attack on the powder metallurgy composite than the liquid infiltration composite as shown in figure 12.

Water Displacing Paint

Typical water displacing paint panels are shown in figure 13. Adhesion was good, but there was some slight corrosion of the basis metal and slight blistering of the paint at the scribe marks. All in all, results were very promising. Additional information on water displacing paint can be found in reference (f).

Laser Hardening Coatings

After eight months of exposure, the adhesion of the laser hardening coatings was found to be excellent. This was an unexpected result because all prior laboratory tests had indicated that the adhesion was exceptionally poor. No explanation can be given for the difference in results.

Accelerated Laboratory Tests

One purpose of the carrier exposures is to develop an accelerated laboratory test that will reproduce the type of attack that occurs on the carrier. With regard to exfoliation of aluminum

alloys, the EXCO test (ASTM G-34) reproduces quite well the attack that took place on the aircraft carrier and other natural environments. However, the EXCO is an immersion test and not suitable for materials such as paints, graphite epoxy composites, and avionics components. Therefore, attempts are being made to find a salt-spray test procedure that can be used for all materials.

In the cyclic SO_2-salt-spray tests, Cycle I, the spray-soak-SO_2 cycle, resulted in very little exfoliation, mainly surface attack even after 30 days of exposure. Cycle II simulated carrier exposure attack more closely than Cycle I with both 7075 and 2124 exfoliating in relatively short times. Cycle III came closest to giving the same type of attack as carrier exposure. The major differences were the somewhat darker color of corrosion products in the laboratory test and a slight reversal of attack. On the carrier, 2124 was more severely attacked than 7075 while the reverse was true in the laboratory test. Cycle IV formed more surface lumps than the other cycles without distinct layering, 2124 was very black after a few days of exposure. Results of cyclic exposure are shown in figures 14 and 15 for cycles I, II, and III.

CONCLUSIONS

1. Severe exfoliation of aluminum alloys, susceptible to exfoliation, takes place in eight months of carrier exposure.

2. The environment of an aircraft carrier, however powered, is considerably more corrosive than seacoast or industrial environments.

3. Climate has a more marked effect on the corrosion of aluminum alloys than the presence or absence of stack gases.

4. The aluminum oxide/aluminum composites tested are resistant to exfoliation and deep pitting.

5. The graphite/epoxy panels tested did not show any unusual or severe effects from the carrier exposure – only the known and expected degradation from moisture absorption.

6. The Vought laser hardening paint system performed better on carrier exposure specimens than the salt spray results indicated it would.

7. Water displacing paint shows promise as a protective system for Naval aircraft.

8. Cycle SO_2-salt spray (Cycle III) simulates carrier exposure attack on bare aluminum alloys.

FUTURE PLANS

A rack has been installed on the U.S.S. America. Several 17-4 PH steel panels with various protective coatings are attached to the rack. Exposure of the 17-4 specimens is being conducted at the request of the Naval Weapons Center in connection with a corrosion problem on Sidewinder missiles. Additionally, the rack contains EMI seal assemblies to determine whether silver or silver plated copper filled silicone rubber seals accelerate corrosion of aluminum alloy avionics boxes. Also on the rack are coatings of IVD aluminum, bright cadmium, dull cadmium and aluminum-manganese on steel panels, assemblies of anodized 7075-T6 aluminum with IVD aluminum, aluminum-manganese, and cadmium coated steel fasteners, water displacing paint on aluminum alloy panels, boron/aluminum composite material, and 7075 and 2124 controls.

Another rack has been installed on a navigation equipment test ship, the U.S.N.S. Vanguard. Although the Vanguard is not the same as a carrier, the specimens will be subjected to salt spray and stack gases, and control specimens of low resistance 7075 and 2124 aluminum alloys are attached to the rack so that comparisons can be made with carrier exposure. It is hoped that, closer monitoring of the specimens will be possible on the Vanguard than it has been on carriers.

At the request of the Naval Air Systems Command, Northrop's Weldbond adhesive bonding process is being evaluated. Wedge opening load specimens of 7075-T6 aluminum alloy are being exposed on the Vanguard rack as part of a program to qualify the process for use on Naval aircraft. Clad and bare 7075-T6 aluminum alloy panels with and without paint are on the Vanguard rack to compare sealed and unsealed anodizing, and chemical conversion coatings as pretreatments for aluminum. More water displacing paint specimens are also included. The corrosion monitor, described in reference (a), has been placed immediately above the rack to measure the intensity of corrosive conditions.

McDonnell Douglas is preparing a series of graphite and aluminum specimens simulating the joints used on F-18 aircraft. These will be exposed on the flight deck of a carrier to observe their behavior under very severe conditions.

Materials other than bare aluminum alloys will be exposed to cycle III of cyclic SO_2-salt spray and compared with specimens of the same materials exposed on carriers.

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(a) AIRTASK No. WF61-542-001, Work Unit No. ZM501, Shipboard Exposure Testing.

(b) E.J. Jankowsky, S.J. Ketcham, V. S. Agarwala, Aircraft Carrier Tests of Aluminum Alloys, Report No. NADC-79251-60 of 1 Nov 1979.

(c) NADC Contract No. N62269-79-C-0257, Corrosion Control Test Methods for Avionics Components.

(d) AIRTASK No. WF61-542-001, Work Unit No. ZM501, Development of Water Displacing Paint.

(e) D.O. Sprowls, T.J. Summerson, and R.I. Lindberg, Exfoliation Corrosion Testing of High Strength Aluminum Alloys in the Atmosphere, ASTM Symposium on Atmospheric Corrosion, May 1980, to be published in ASTM STP.

(f) C.R. Hegedus, Development of a Water Displacing Touch-Up Paint, Report No. NADC-80207-60 of 24 Feb 1981.

Table I. Aluminum Alloys used for Exfoliation Tests

Alloy/Form	Temper	Thickness mm (in.)	Expected Resistance to Exfoliation	Dimensions mm (in.)
2124 Plate	T851	12.2 (0.5)	High	76 x 152 (3 x 6)
	T351	12.2 (0.5)	Intermediate	76 x 152 (3 x 6)
	T351 + 0.5 hrs at 375° F	12.2 (0.5)	Low*	76 x 152 (3 x 6)
	T851	50.8 (2.0)	High	76 x 152 (3 x 6)
	T351	50.8 (2.0)	Intermediate	76 x 152 (3 x 6)
	T351 + 0.5 hrs at 375° F	50.8 (2.0)	Low	76 x 152 (3 x 6)
7075 Extrusion		12.2 (0.5)	High	76 x 76 (3 x 3)
			Intermediate	76 x 76 (3 x 3)
			Low*	76 x 76 (3 x 3)
7178 Sheet	T6	2.3 (.091)	Low	76 x 152 (3 x 6)
	T6 + 10 hrs at 325° F		Intermediate	76 x 152 (3 x 6)
	T6 + 11 hrs at 325° F		High	76 x 152 (3 x 6)

*Only these two materials were exposed on the U.S.S. Constellation

Table II. Exfoliation Ratings (ASTM G34-79)

	Conventional Carrier (Kennedy) 4 Mos.	Conventional Carrier (Kennedy) 8 Mos.	Nuclear Carrier (Nimitz) 10 Mos.	Conventional Carrier (Constellation) 8 Mos.
2124 – 12.2 MM (0.5 In.) Plate				
Low Resistance				
T/10	EA	ED	ED	ED
T/2	EA	EC	ED	ED
Intermediate Resistance				
T/10	EA	EC	ED	
T/2	P	P	EC	
High Resistance				
T/10	P	P	P	
T/2	P	P	P	
2124 – 50.8 MM (2 In.) Plate				
Low Resistance				
T/10	EB	ED	ED	
T/4	EB	ED	ED	
T/2	EA	EC	ED	
Intermediate Resistance				
T/10	P	P	EB	
T/4	EA	EC	EC	
T/2	EA	EC	ED	
High Resistance				
T/10	P	P	P	
T/4	P	P	P	
T/2	P	P	P	

P – Pitting

Exfoliation Ratings

A Slight C Severe

B Moderate D Very Severe

Table II. Exfoliation Ratings (ASTM G34-79) (Continued)

	Conventional Carrier (Kennedy)		Nuclear Carrier (Nimitz)	Conventional Carrier (Constellation)
	4 Mos.	8 Mos.	10 Mos.	8 Mos.
7075 – 12.2 MM (0.5 In.) Extrusion				
Low Resistance				
T/10	EB	ED	ED	EC
T/2	EA	EB	EC	EB
Intermediate Resistance				
T/10	EA	EB	EB	
T/2	P	P	EA	
High Resistance				
T/10	P	P	P	
T/2	P	P	P	
7178 – 2.3 MM (0.091) In. Sheet				
Low Resistance				
T/10	EA	ED	ED	
Intermediate Resistance				
T/10	P	P	PB	
High Resistance				
T/10	P	P	P	

P – Pitting

Exfoliation Ratings

A Slight C Severe

B Moderate D Very Severe

Table III. Results of Tests of Graphite/Epoxy Composite

Panel Identification & Test Temperature	Tensile Strength PSI	Shear Strength PSI	Flexural Strength PSI
Unpainted			52267
Unexposed		6233	51836
		6241	51878
UCAR-5	56921	6450	54584
R.T.	59334	6253	52967
	51239	6110	55862
Avg.	55831	6257	53232
			52019
		5965	49920
		5740	52092
UCAR-6	57004	6438	55063
180° F	55537	5852	50208
	59755	5824	55030
Avg.	57432	5964	52389
			48334
		5966	54461
		5970	51810
UCAR-7	62078	5910	57526
250° F	60217	6737	54569
	60756	5960	54569
Avg.	61016	6108	53544
Painted & Exposed			
Aboard Nimitz			
			53545
		5918	58516
CAR-2		6312	57306
R.T.	64153	5918	57628
	55669	5852	51571
	56640	6075	60367
Avg.	58821	6015	56489
			57930
		6963	61798
CAR-3		7399	57631
180° F	66442	6579	56842
	59945	6516	60677
	63490	6577	64719
Avg.	63292	6807	59933

Table III. Results of Tests of Graphite/Epoxy Composite (Continued)

Panel Identification & Test Temperature	Tensile Strength PSI	Shear Strength PSI	Flexural Strength PSI
CAR-4 250° F	54238 60249 58815	4315 4152 4285 4353 4278	45567 47517 50323 52419 52190 47131
Avg.	57767	4276	49191
Change	-2%	-29%	-13%
Weight, Grams	CAR-2		
After Exposure	189.99		
Before Exposure	188.68		
	1.31		
% Moisture Pickup	0.6		
Painted & Exposed Aboard Constellation			
CAR-1 R.T.	59583 64712 64470	5617 6173 6530 6184 6242	53228 53808 52803 51322 48286 53619
	62922	6149	52178
CAR-5 180° F	59780 63758 61482	6343 6103 6429 6252 5559	47078 45097 45553 49824 47041 48922
	61674	6137	47253
CAR-6 250° F	58462 60757 61113	6060 5847 5894 5707 6090	44824 46434 46123 48301 45144 46159
	60111	5920	46164
Change	-4%	-4%	-12%

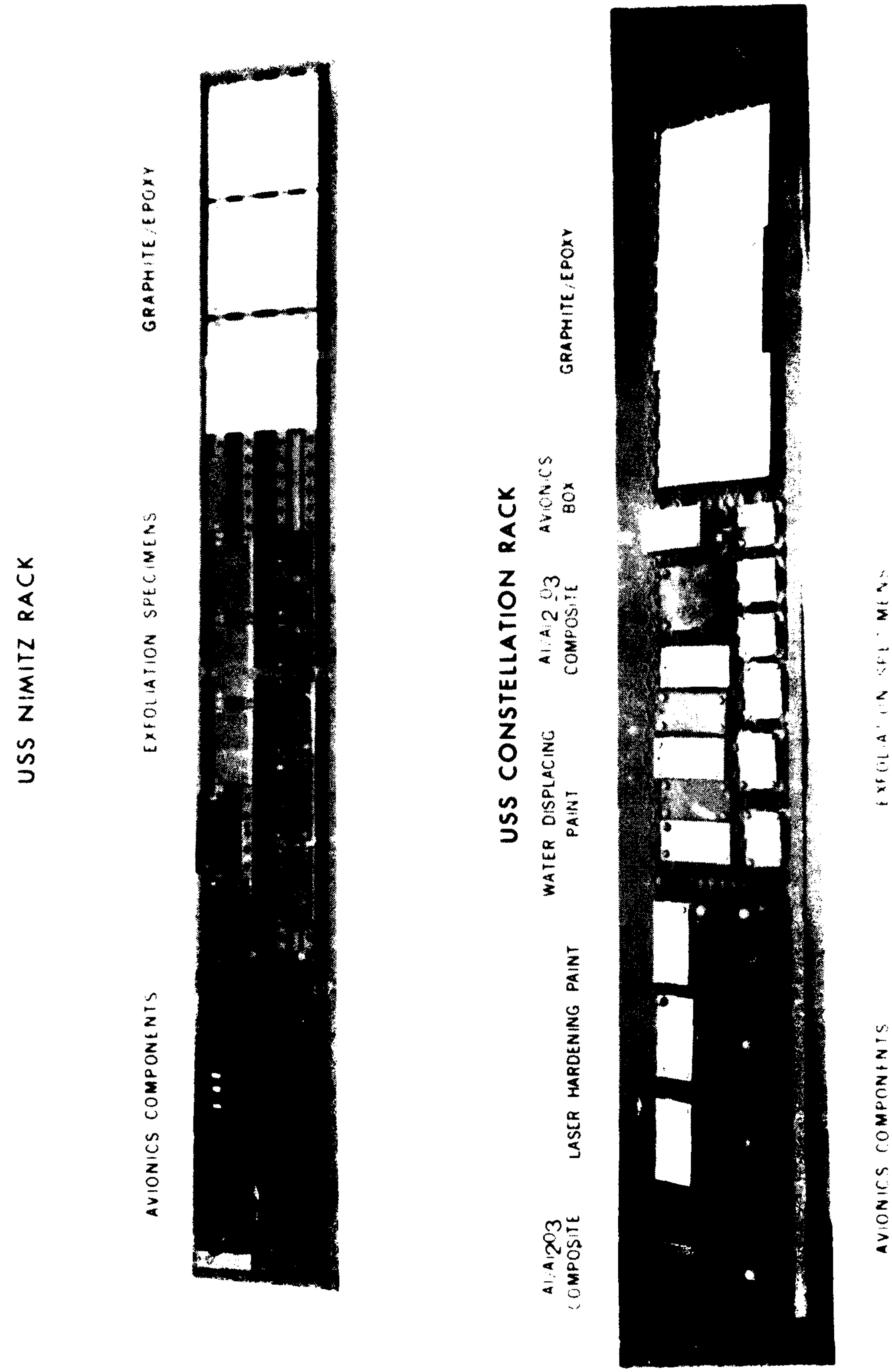


Figure 1. Carrier Exposure Racks

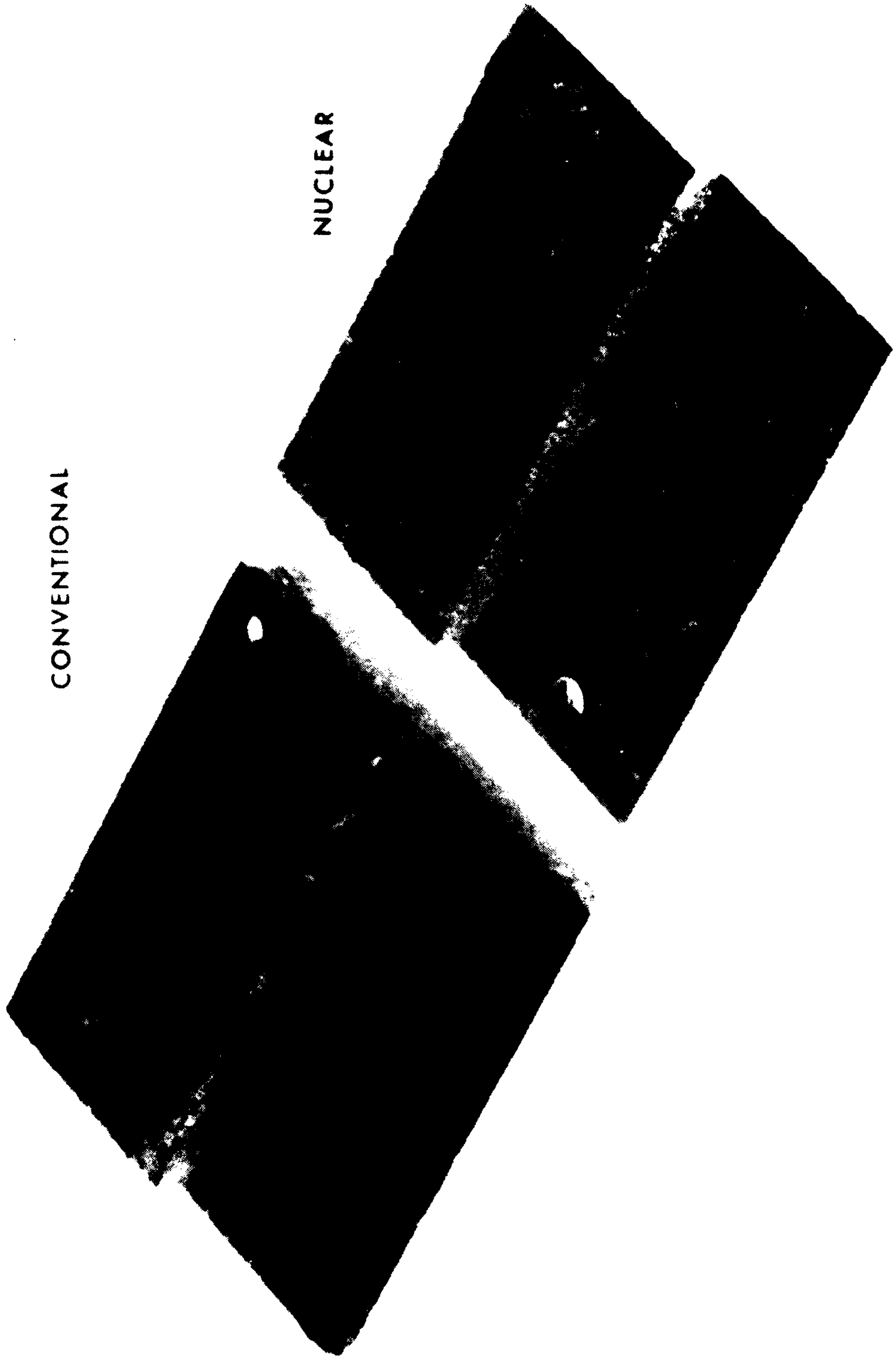


Figure 2. Comparison of Exposure Panels from Nuclear and Conventional Carriers
7075 - 0.5 Inch Extrusion, Low Resistance

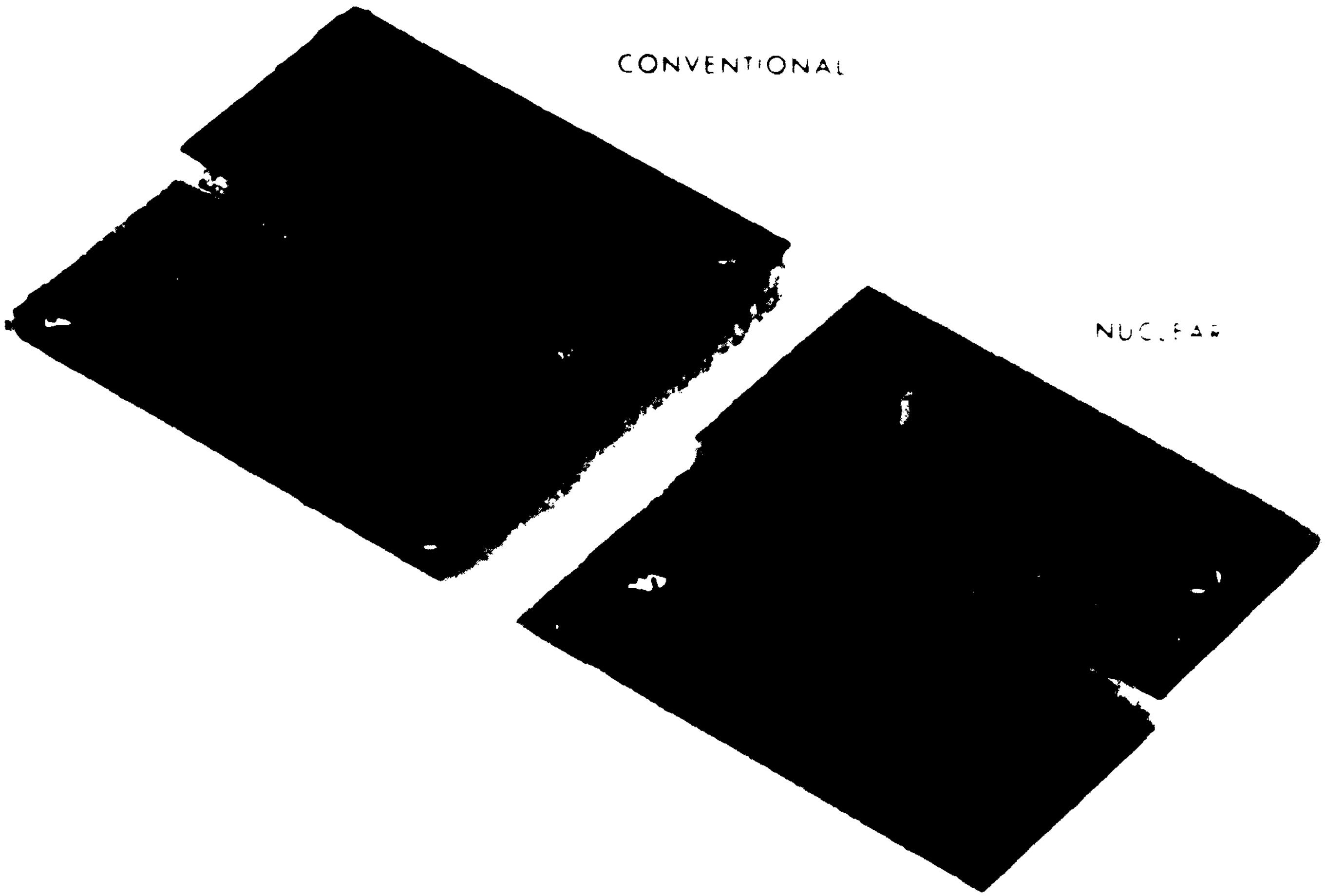


Figure 3. Comparison of Exposure Panels from Nuclear and Conventional Carriers
7075 - 0.5 Inch Extrusion, Intermediate Resistance

Figure 4. Comparison of Exposure Panels from Nuclear and Conventional Carriers

2124 - 2 Inch Plate, Low Resistance

Figure 5. Comparison of Exposure Panels from Nuclear and Conventional Carriers

2124 – 2 Inch Plate, Intermediate Resistance

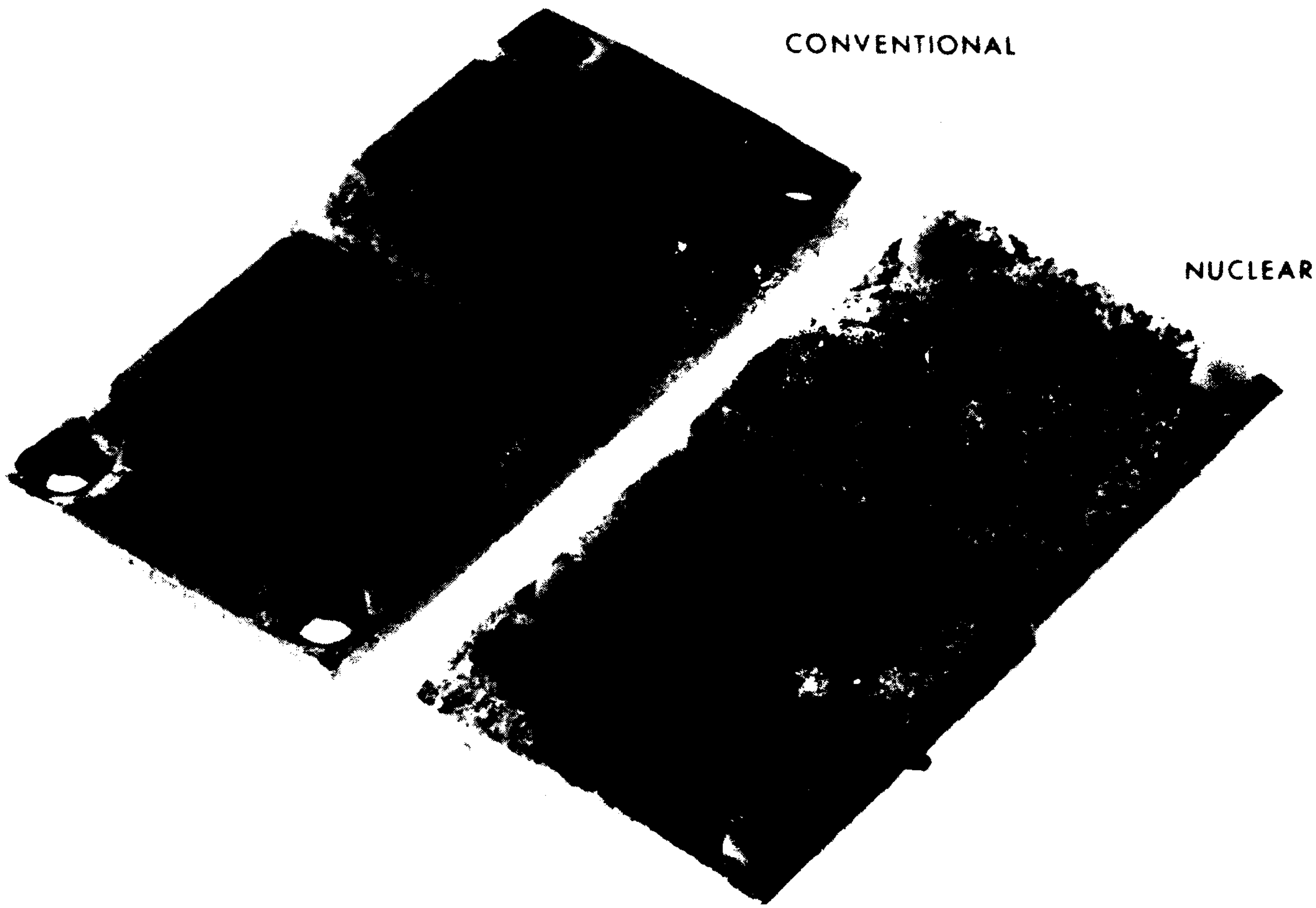


Figure 6. Comparison of Exposure Panels from Nuclear and Conventional Carriers

2124 - 0.5 Inch Plate, Low Resistance

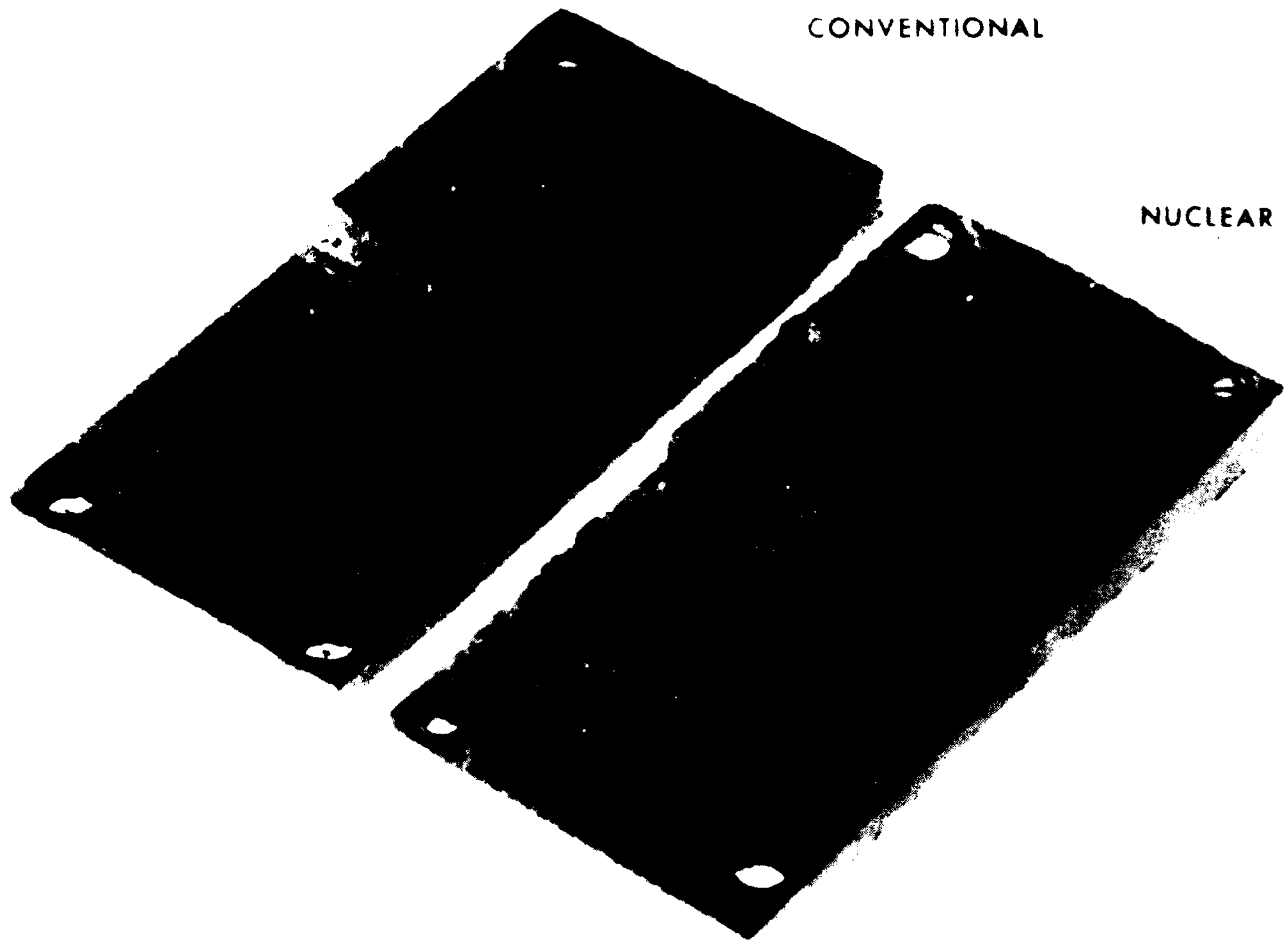


Figure 7. Comparison of Exposure Panels from Nuclear and Conventional Carriers

2124 - 0.5 Inch Plate, Intermediate Resistance

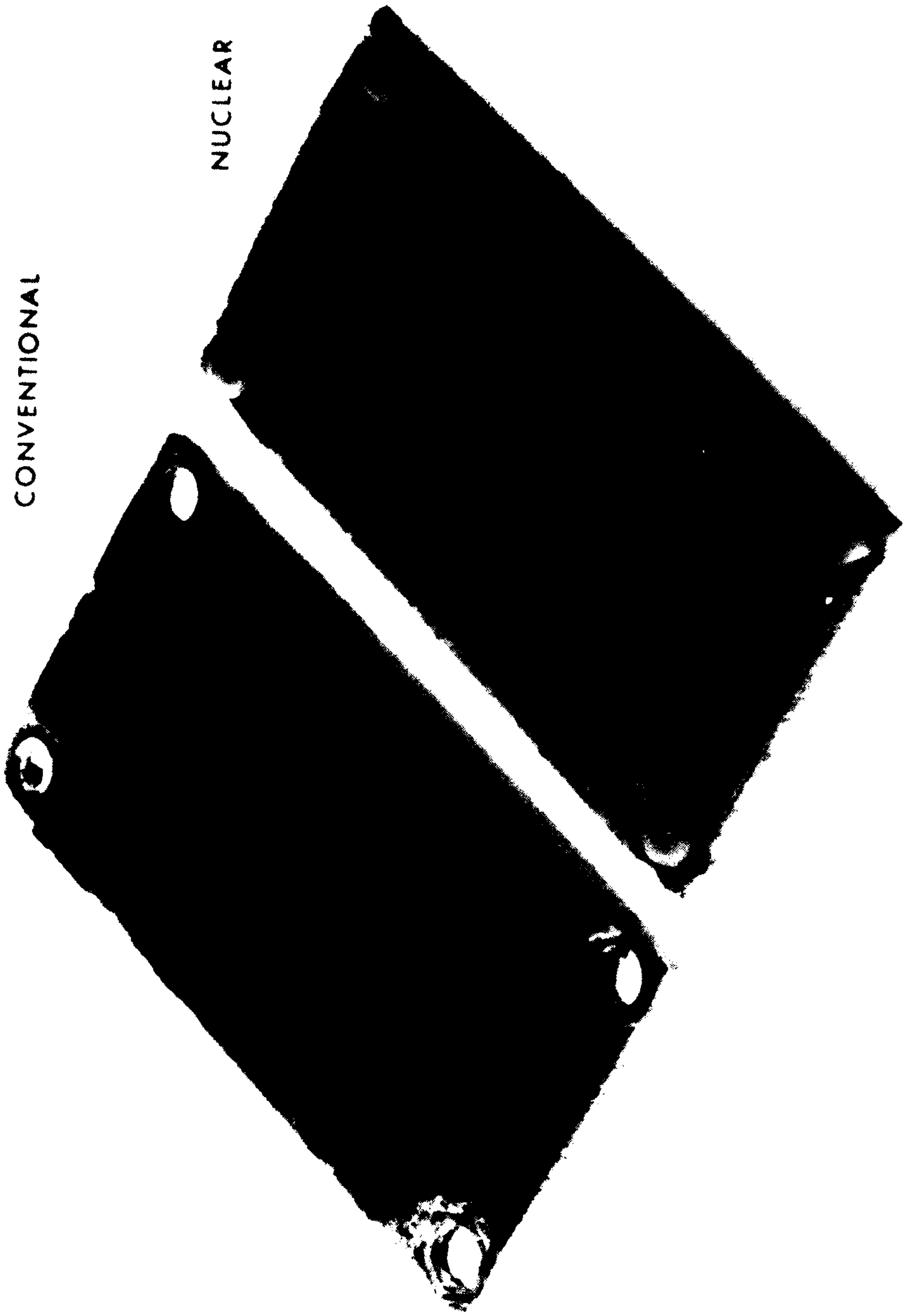


Figure 8. Comparison of Exposure Panels from Nuclear and Conventional Carriers

7178 - .091 Inch Sheet, Low Resistance

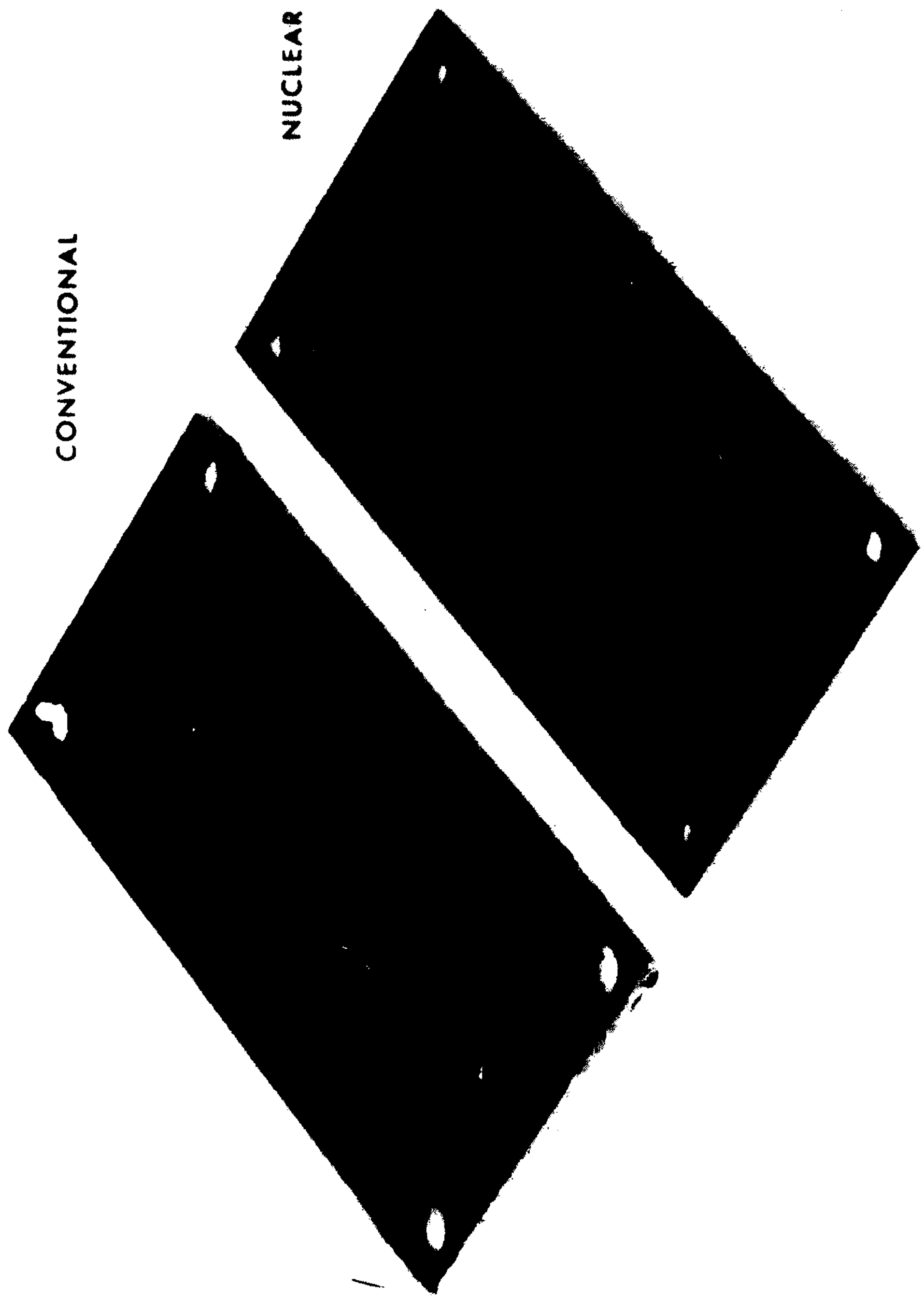


Figure 9. Comparison of Exposure Panels from Nuclear and Conventional Carriers
7178 - 0.091 Inch, Intermediate Resistance

8 MONTHS ON CONVENTIONAL CARRIER

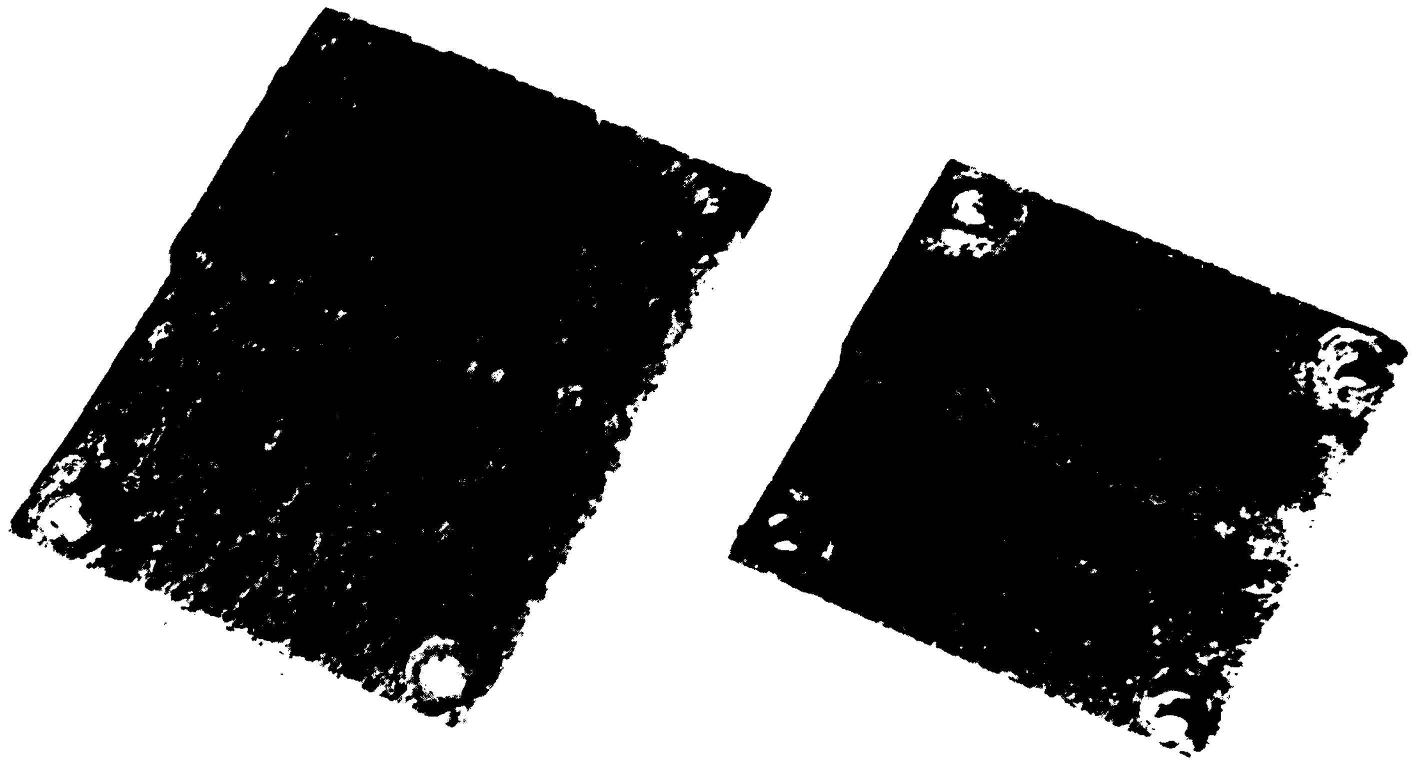


Figure 10. Typical Exposure Panels from U.S.S. Constellation

2124 - 0.5 Inch Plate, Low Resistance, 7075 Extrusion, Low Resistance

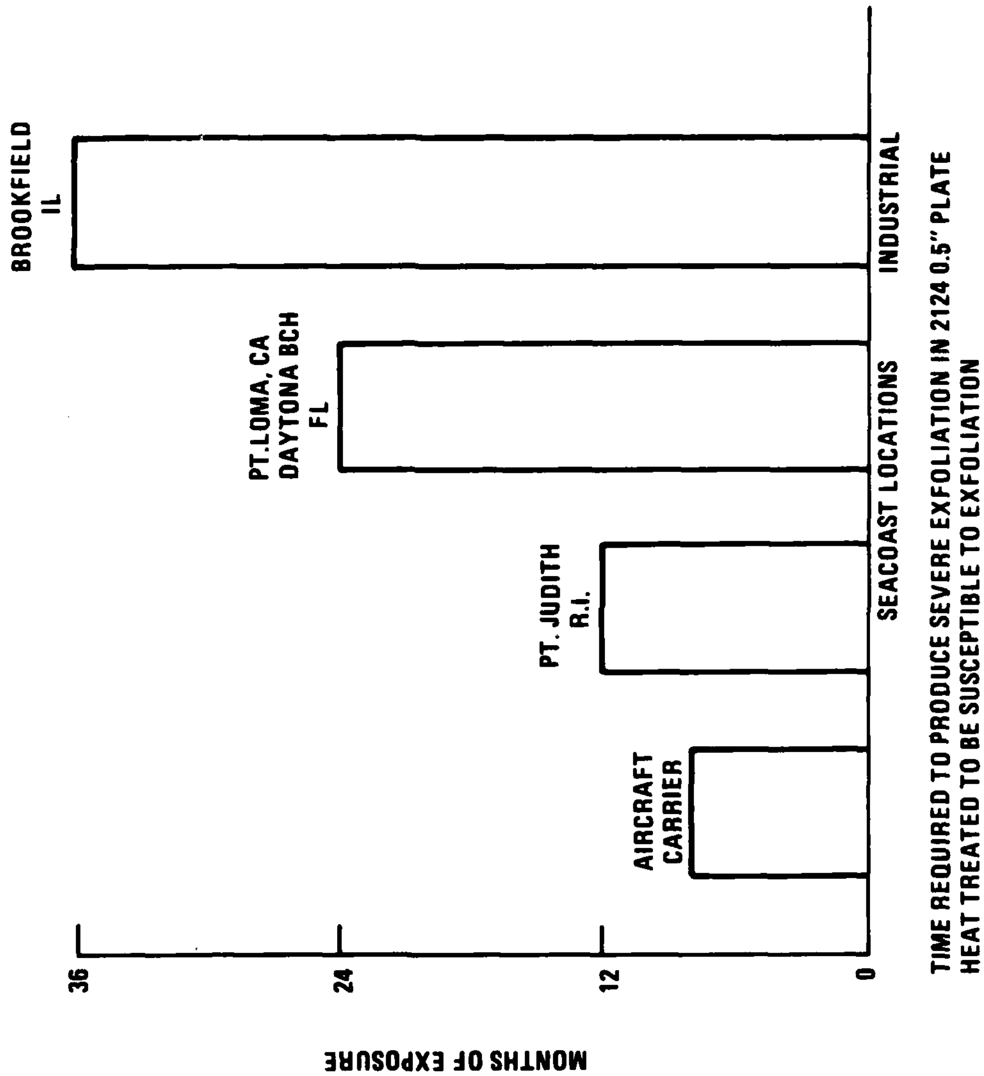
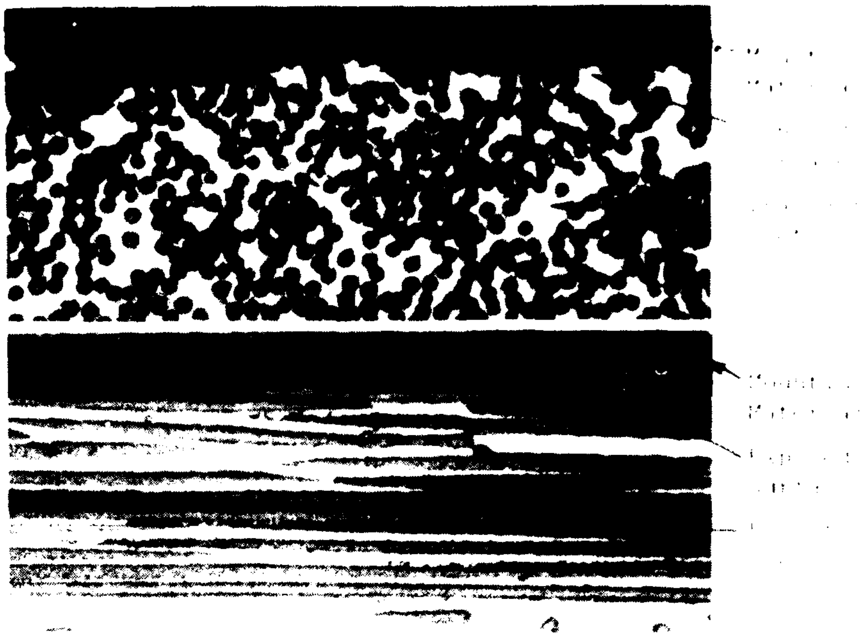
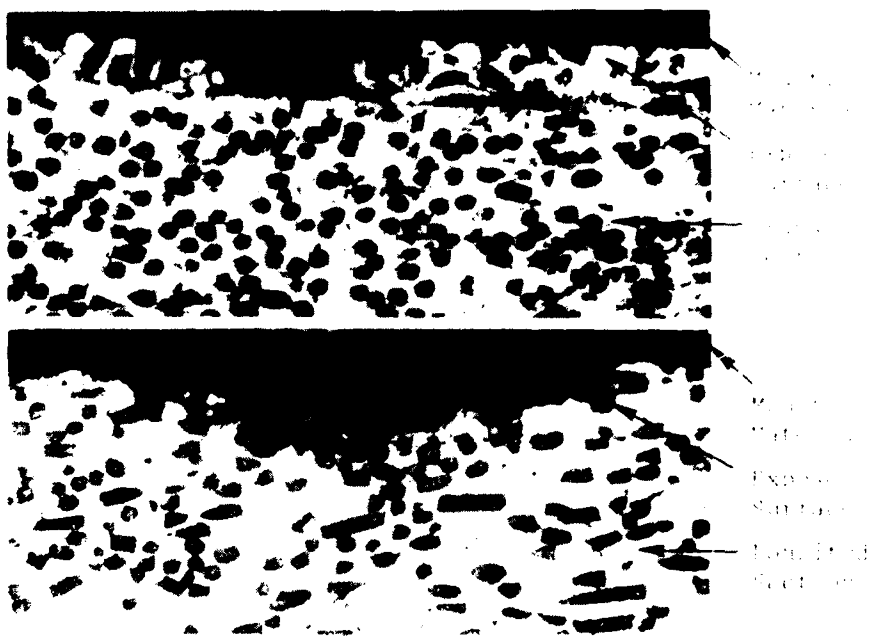


Figure 11. Comparative Corosivity of Environments



LIQUID INFILTRATION COMPOSITE 100 X



POWDER METALLURGY COMPOSITE 100 X

Figure 12. Photomicrographs of Aluminum/Aluminum Oxide Composites

AS REMOVED DETERGENT CLEANED AFTER WDP REMOVED

NOTE: DARK SPOTS ON PANEL B - ACCIDENTAL PAINT SPLATTER DURING EXPOSURE PERIOD

Figure 13. Water Displacing Paint (WDP) Exposure Panels from U.S.S. Constellation
After Eight Months of Exposure

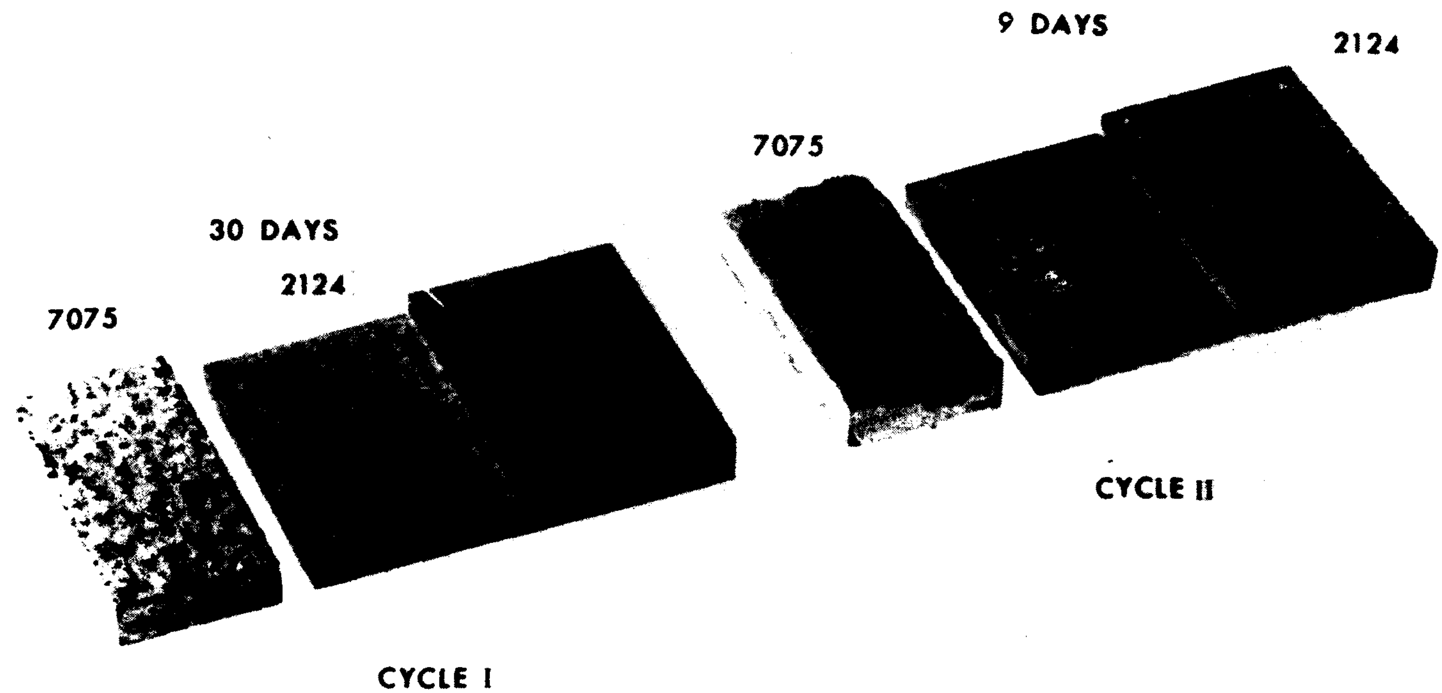


Figure 14. Cycle I and Cycle II – Cyclic SO_2 – Salt Spray

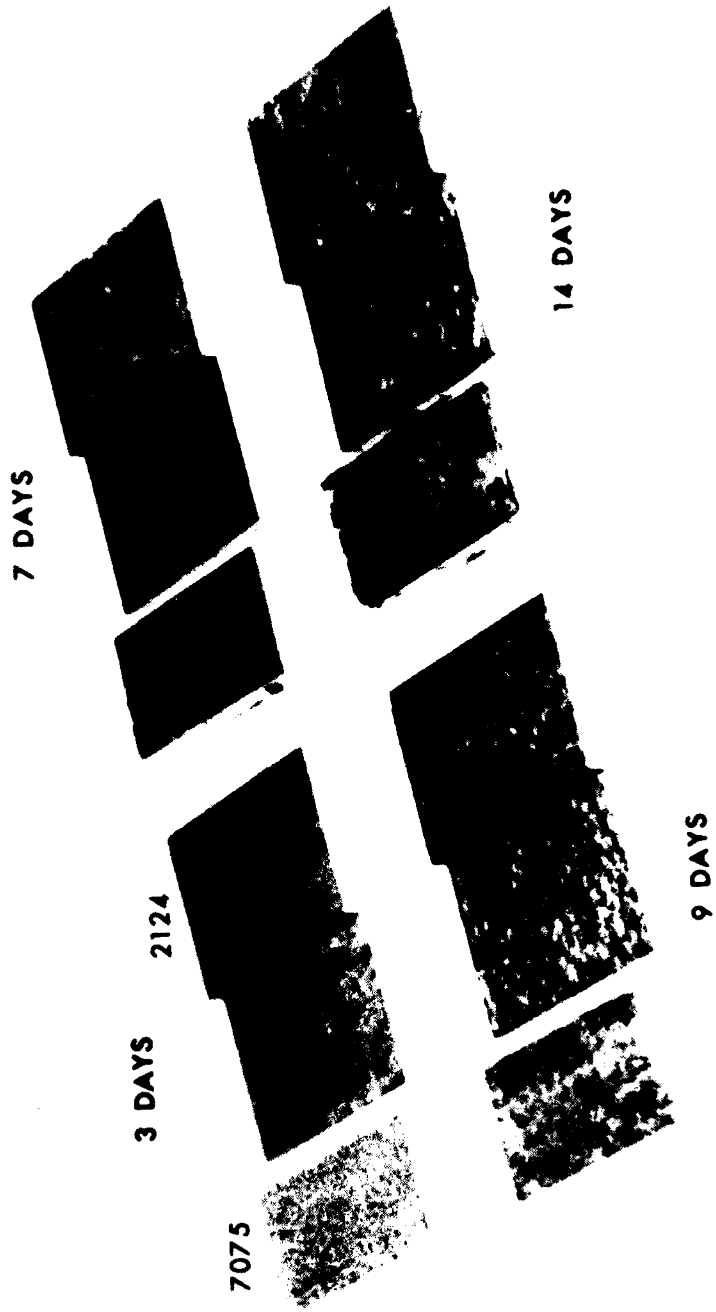


Figure 15. Cyclic III — Cyclic SO_2 — Salt Spray

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